

# *Abstract for Cocoa Beach Restricted Sessions, 2006*

## **Modeling Creep Effects in Advanced SiC/SiC Composites**

J. Lang \* and J. DiCarlo

NASA Glenn Research Center, Cleveland, OH

Because advanced SiC/SiC composites are projected to be used for aerospace components with large thermal gradients at high temperatures, efforts are on-going at NASA Glenn to develop approaches for modeling the anticipated creep behavior of these materials and its subsequent effects on such key composite properties as internal residual stress, proportional limit stress, ultimate tensile strength, and rupture life. Based primarily on in-plane creep data for 2D panels, this presentation describes initial modeling progress at applied composite stresses below matrix cracking for some high performance SiC/SiC composite systems recently developed at NASA. Studies are described to develop creep and rupture models using empirical, mechanical analog, and mechanistic approaches, and to implement them into finite element codes for improved component design and life modeling.



# ***Modeling Creep Effects in Advanced SiC/SiC Composites***

**J. Lang and J. DiCarlo  
NASA Glenn Research Center  
Cleveland, Ohio**

***Research Supported by the  
NASA Glenn Internal Research & Development Fund***

**Presented at 30th Annual Conference  
on Composites, Materials, and Structures  
RESTRICTED SESSIONS  
Cape Canaveral, Florida, January 25, 2006**



## ***Background***

**A variety of advanced SiC/SiC composite systems have been developed by NASA for aerospace components that will experience long-term service to temperatures above 2200°F under high thermal and stress gradients**

**Under these conditions, effectively all SiC/SiC systems will display measurable creep that may or may not contribute to component failure. *These creep-related mechanisms need to be understood and modeled for successful component service***



## ***Some SiC/SiC Creep Effects of Technical Concern***

- Adverse dimensional changes: ***not usually significant because SiC/SiC will typically rupture at very low creep strains (less than 0.5%)***
- Adverse intrinsic flaw growth in fibers and matrix leading to constituent and CMC rupture: ***data and models are growing at NASA, but much work still needed***
- Adverse residual stress development in a component due to thermal and stress gradients: ***could be a significant beneficial or detrimental factor at strain levels well below CMC rupture and at stresses below matrix cracking***



## ***Objectives / Outline***

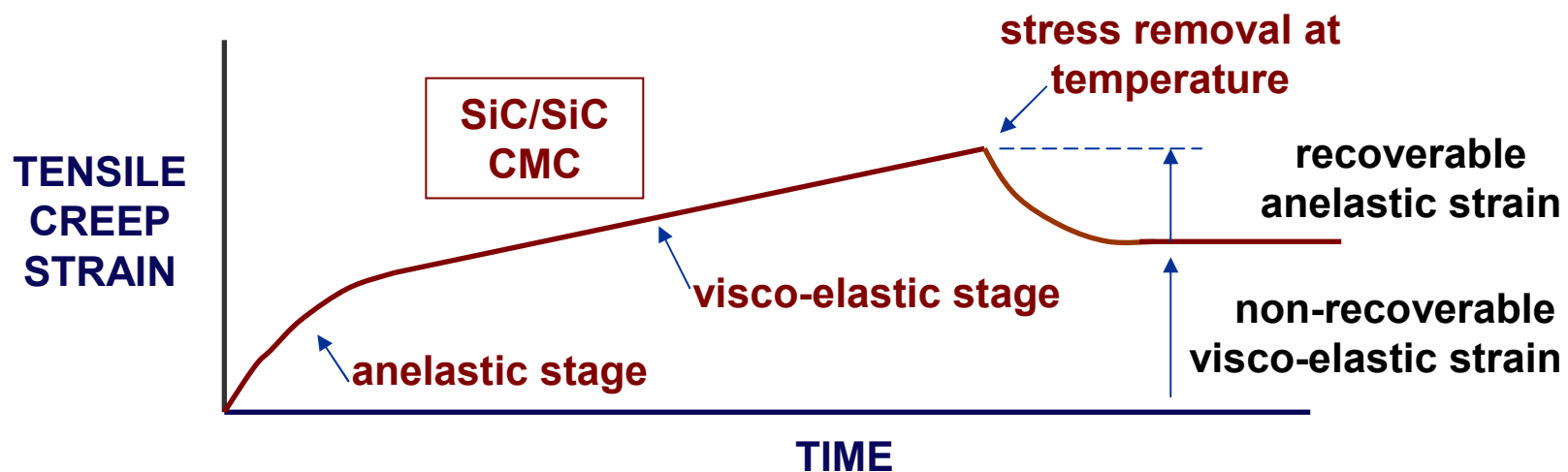
- **Discuss the basic mechanisms controlling creep of SiC/SiC composites**
- **Present a general in-plane analytical creep model for 0/90 SiC/SiC panels and for finite element code analysis of SiC/SiC components**
- **Discuss briefly how models can be used for understanding some creep-related effects of technical concern for SiC/SiC components**
  - **Intrinsic tensile rupture at high temperatures**
  - **Residual stress development in cooled walls with high thru-thickness thermal gradients**
  - **In-plane finite element modeling of panels with holes**
- **Describe studies needed for further understanding creep effects in high temperature SiC/SiC components**

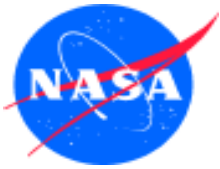


## ***Basic Mechanisms of SiC/SiC Creep***

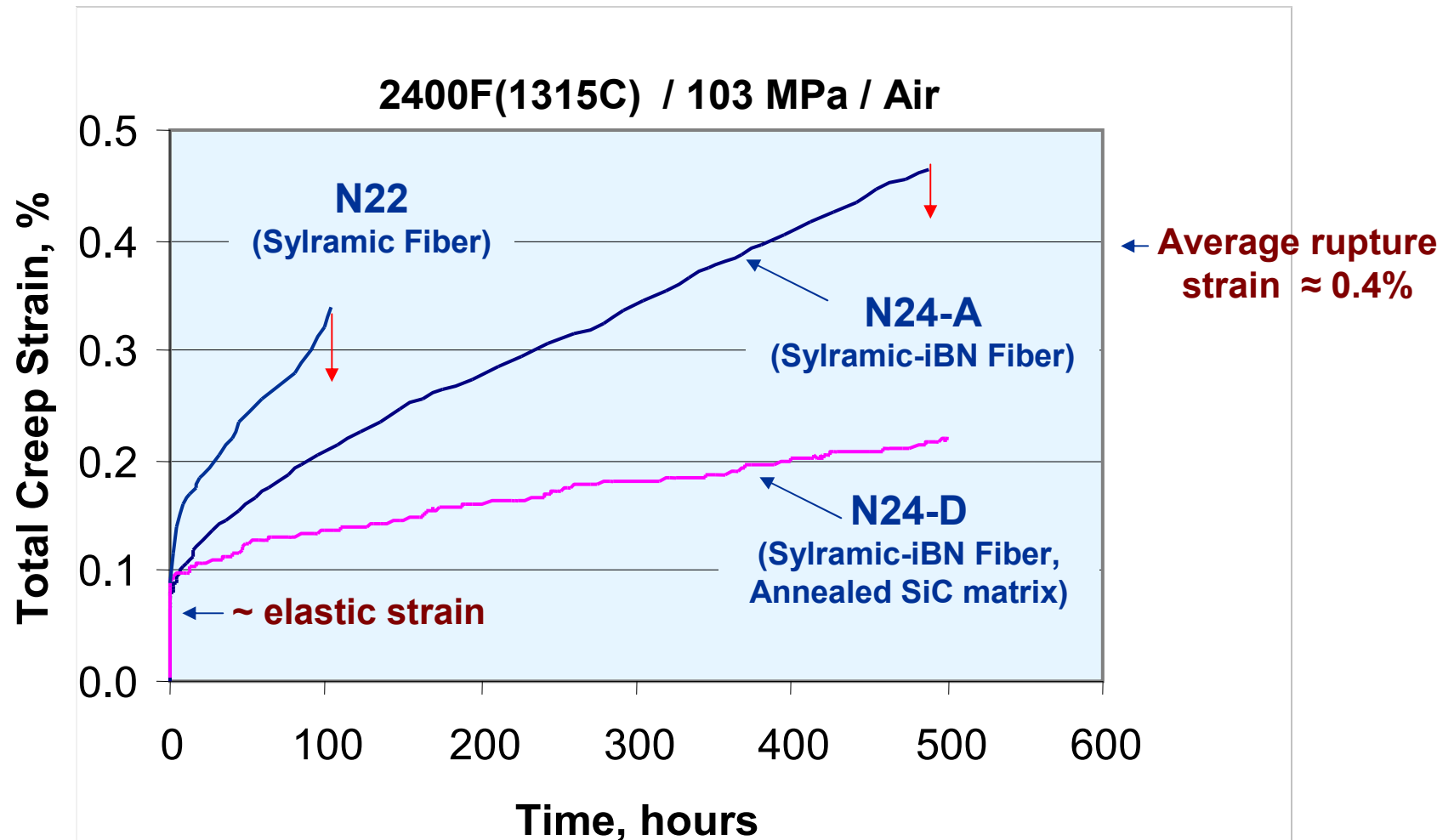
### ***General Constituent Behavior (multiple NASA references):***

- **SiC fibers display two components to creep strain:**
  - A transient or anelastic (recoverable) strain that saturates with time
  - A near steady-state or visco-elastic (non-recoverable) strain
- **Both components are controlled by atomic diffusion at the grain boundaries, but only the viscoelastic component controls intrinsic flaw growth and high temperature rupture**
- **Dense SiC-based matrices display same mechanisms as SiC fibers, but generally creep at a different rate due to stress and compositional differences (Creep Mismatch Problem)**





## ***Typical In-Plane Tensile Creep-Rupture Behavior in Fiber Direction for Some Advanced NASA-Developed 2D 0/90-balanced SiC/SiC Panels***





## ***Analytical Model for In-Plane SiC/SiC Creep***

- Mechanistic theory and ***limited*** test data below matrix cracking have been used to develop the following general equation for predicting creep in fiber (x) direction for balanced 2D 0/90 SiC/SiC panels ***under constant stress and temperature conditions***:

$$\epsilon_x \approx [\epsilon_{ex}] \cdot [1 + A_x \cdot \{1 - \exp(-t/\tau)\} + A_x \cdot \{t/8\tau\}]$$

$\epsilon_x$  = total creep strain (***assumed linear with stress  $\sigma_x$*** )

$\epsilon_{ex}$  = elastic strain =  $\sigma_x / E_x$

$E_x$  = system-dependent elastic modulus

$\tau$  = temperature-dependent parameter (based on SiC)

$\ln \tau = (52000/T) - 29.7$  ( $\tau$  = hours,  $T$  = Kelvin)

**$A_x$  = system-dependent creep parameter**





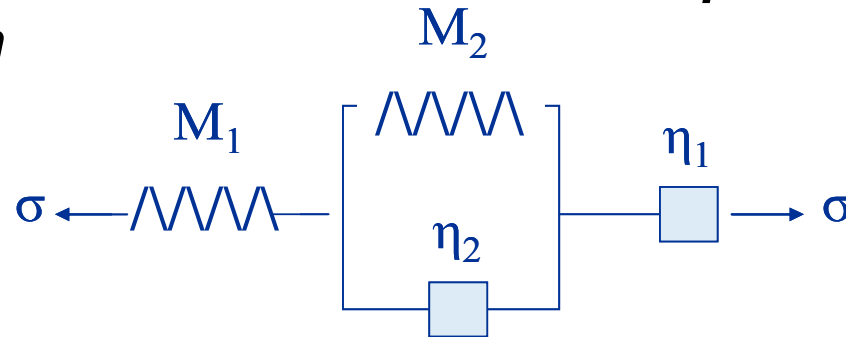
## Comparison of the Best Fit Creep Parameters $A_x$ for Advanced SiC/SiC Systems

	Nicalon /CVI-SiC	NASA N22	NASA N24-A	NASA N24-D	NASA N26
Upper Use Temperature	2000°F	2200°F	2400°F	2400°F	2600°F
Fiber	Nicalon	Sylramic	Sylramic- iBN	→	→
Matrix A	CVI SiC	→	→	CVI SiC (anneal)	→
Matrix B	CVI SiC	Slurry SiC + MI Si	→	MI Si	PIP SiC (anneal)
$A_x$ CMC Creep Parameter	~3	3.2	2.0	0.4	0.08
Controlling Constituent	matrix	fiber	fiber	matrix	matrix



## ***SiC/SiC General Deformation and Finite Element Models***

**Approach:** (1) *Fit constant  $\sigma$  and  $T$  creep equation for SiC/SiC to a Four-Parameter mechanical analog for a more general description of SiC/SiC stress/time/temperature-dependent deformation*



(2) *Using general model from four-parameter analog, develop stress relaxation “Prony Series” for implementation into ANSYS finite element code. For example, for N24-A,*

$$G/G_o = 0.70 \exp(-t/a\tau) + 0.30 \exp(-t/b\tau)$$

where  $a = 0.19$  and  $b = 7.6$



## Creep-related Technical Effect: *Intrinsic SiC/SiC Rupture at High Temperatures*

- *At high temperatures and stresses below matrix cracking, NASA has demonstrated that SiC/SiC CMC rupture follows the **Monkman-Grant empirical relationship** so that the viscoelastic or steady-state component  $\dot{\epsilon}_{ss}$  of the general analytical creep model can be used to estimate CMC rupture time as a function of stress and temperature:*

$$t \text{ (rupture)} \approx C(T) \cdot [\dot{\epsilon}_{ss}]^{-m}$$

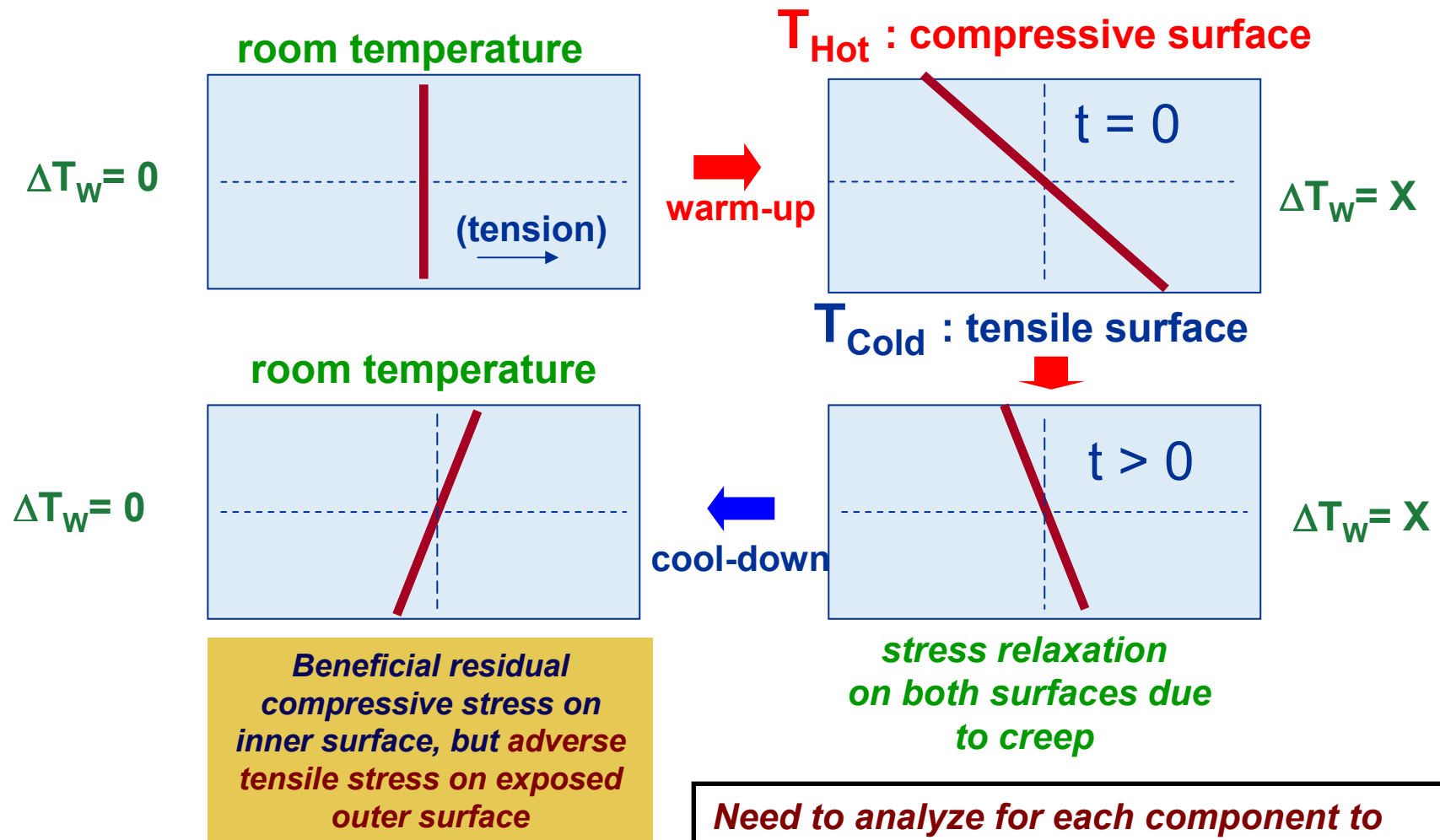
$C(T)$  = empirically determined constant

$$m = 1.2$$

$$t \text{ (hrs)} \approx C(T) \cdot \{[8E_x / A_x \sigma_x] \cdot 10^{-12} \exp(52000/T)\}^{-1.2}$$



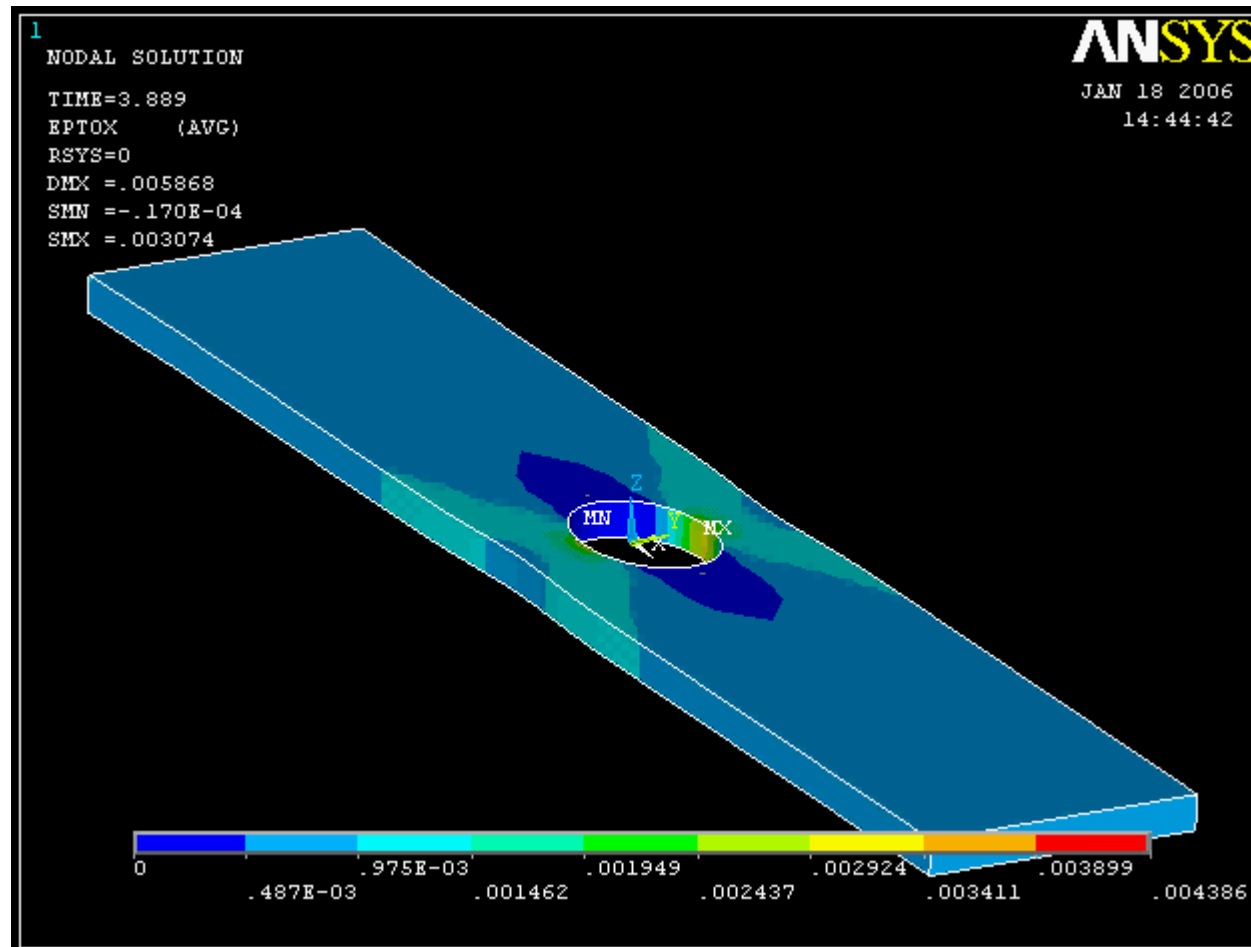
## Creep-related Technical Effect: *Residual Stress Development thru Wall Thickness for Cooled Components*



*Need to analyze for each component to determine whether creep is "friend or foe"*



**Creep-related Technical Effect:**  
***Strain Changes around Holes in N24A SiC/SiC***  
***2400°F; 103 MPa***





## Summary

- Using limited creep data measured on 0/90 panels at constant stress levels below matrix cracking, NASA has developed ***a general analytical 0° creep strain equation*** for a variety of advanced SiC/SiC systems
- This equation has been used to develop:
  - a more general stress/time/temperature-dependent SiC/SiC deformation model by way of a four-parameter mechanical analog
  - a general stress-relaxation Prony series for implementation of SiC/SiC creep behavior into finite element codes
  - an approach for modeling intrinsic SiC/SiC rupture at high temperatures
  - an approach for understanding residual stress development in SiC/SiC components with stress gradients, such as those that are cooled thru the thickness or have holes under stress



## ***Creep-Related Research Needs (on-going studies at NASA)***

- From a ***modeling point-of-view***, significantly more data and models are needed for existing SiC/SiC systems:
  - Stress dependencies for creep at lower stress levels
  - Compression creep (monolithic Si-containing SiC known to creep much less in compression)
  - In-plane off-axis creep
  - Thru-thickness creep behavior
  - Architectures other than 2D 0/90
  - Creep above matrix cracking
  - Constituent-based and architecture-based micromechanical creep models
- From a ***materials point-of-view***, constituents and architectures need to be developed that can provide SiC/SiC systems with as high a creep resistance as possible to avoid potential adverse effects